with pin spacing of about 0.5 mm thus providing 400 pins in a 20 pin by 20 pin array (about a one square centimeter array).

[0040] The fingertip display of this invention creates the impression of an extended tactile image by creating the illusion of the fingertip scanning across an extended surface. While a computer controlling the display could drive the apparent scanning motion of the tactile image independent of any input from the user, in practice this approach creates a poor sense of realism, and is rated poorly by users. The sense of touch is activated most realistically in a fingertip by coupling apparent motion of display array **15** to real motion of the finger, so that motion of the finger to the right, for example, results in propagation of the tactile image from right to left at array **15** (reproducing the sensation that the finger would feel when moving left to right on a real surface), with the same counter-motion principle applying to motion of the fingertip in any direction across a virtual surface.

[0041] For a flat display on a horizontal surface, this can be accomplished by mounting fingertip display array **15** on a tracking device **21** comparable to a computer mouse that senses motion of the fingertip and updates the output of array **15** accordingly (as shown in **FIG. 2**).

[0042] For virtual reality and augmented reality applications, a fingertip display array **15** is mounted at a finger or fingers (including the thumb) of data glove **23** (see **FIG. 3**). In such case, the tracking of finger motion is performed in three dimensions by normal operation of the data glove, and any time the finger touches or moves over a virtual surface in the virtual space, the fingertip array **15** produces a sensation in the finger or fingers corresponding to what should be felt by touching the surface, particularly the detailed texture and shape of the surface. Positional tracking should be sufficiently accurate to allow the material being displayed to be acceptably consistent with the position of the glove. For improved realism, a haptic display system of known design could be combined with the fingertip display array of the data glove so that the user feels not only the surface texture but also the resistance of the surface (for example, a hard surface like a rock or a soft surface like an orange). Where multiple arrays **15** are positioned at data glove **23**, the tracking system must observe the spacing between the fingers and assure that the patterns displayed on these multiple fingertips are consistent with the spacing between the fingers.

[0043] Still another option for mounting of array **15** and virtual surface scanning includes utilization of a lateral pressure sensitive scanning control and feedback mechanism that can use measurement of lateral pressure of the finger or other body contact location against the mechanism (i.e., the mechanism does not physically move across a surface) to control direction and speed of scanning over the virtual surface displayed (similar in nature to the control button that is used in some notebook computers instead of a touch pad or track ball for cursor control). This implementation will provide the unique capability of allowing the lateral pressure of the display apparatus against the skin to serve in place of the lateral pressure that would be exerted against the skin by the friction of motion over a real surface. The rate of virtual motion can be adjusted to be a function of the coefficient of friction of the virtual surface and of the pressure applied by the finger perpendicular to such surface.

[0044] Stimulation of the points at the localized area of the user's body by the pins or other stimulus deployed in this invention to represent tactile information is achieved with pressure-driven stimulus rather than fixed linear displacement of pins. Pressure-based stimulus has several advantages over displacement-based stimulus. If pins are used as the stimulus, they can be made to conform to the shape of the individual user's finger by advancing the pins until the desired pressure against the finger is achieved (initially, for example, a default pressure at the default—stimulus neutral—position and thereafter as needed to convey the scanned virtual image). Stimulus can be applied using a curved or flexible surface, which would be more difficult in displacement-based systems. Reliability is greater for pressure-based stimulus; a failed stimulus point simply means one missing stimulus (i.e., no stimulus point would be likely to be stuck in an extended mode thus interfering with the sensation of other stimulus points). In the pressure-based system of this invention there is no need for a return mechanism for pins **17** unlike displacement-based systems, since the application of pressure drives the pins while the absence of pressure allows the resilience of the skin of the user to return the pin to the default, stimulus neutral, position.

[0045] Energy source **25** for a pressure-based system may take many forms, though fluid such as compressed air or other gas or liquid is preferred and allows the energy source to be some distance from fingertip display array **15**. Multiple operational lines (air/liquid channels, for example) **27** can be used to operate individual stimulus points **17** of array **15** with modulator **29** (a control mechanism for operation of the various stimulus points such as a flow regulating valve array for example) being located physically remote from the user's body (at energy source **25**, for example) and supplied by main (fluid supply main, for example) **31** (see **FIGS. 4 and 5**). Alternatively, modulator **29** might be completely local (onboard mouse-type device **21** or data glove **23**) and directly associated with stimulus points **17** of array **15** at an interface complex **33** (for example, with various valves in a valve array operable directly at a cylinders' **35** inlets **37** at pin assemblies **39** of the type shown in **FIG. 6**), thereby making operational lines **27** unnecessary.

[0046] The pressure-based system of this invention also provides flexibility for the system to emulate other stimulus methods. For example, rapid modulation of pressure of the working fluid at stimulus points **17** will produce stimulus point vibration. Position feedback (for example capacitive readout) of stimulus point (pins, for example) positions can be used to control modulation of stimulus points to set, prespecified displacements or refine stimulus point position, thus emulating and improving upon the function of a displacement-based display. These three types of stimulus (pressure, vibration, and displacement) can be used in combination on a pressure-based display to convey different types of tactile information (for example, with pressure used to convey information about the physical texture of a surface, vibration used to convey information such as temperature of the surface or to represent actual vibration, and set position displacement used to convey program information or identify otherwise sensory nonspecific information such as a point on a graph).

[0047] Turning to **FIGS. 5 through 11**, particular embodiments of the pressure-based refreshable scanning tactile